US012276580B2

(12) **United States Patent**
Wu et al.

(10) **Patent No.: US 12,276,580 B2**
(45) **Date of Patent: Apr. 15, 2025**

(54) **PUMP HEALTH ANALYSIS METHOD AND PUMP HEALTH ANALYSIS DEVICE USING THE SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 328 days.

(21) Appl. No.: **17/983,423**

(22) Filed: **Nov. 9, 2022**

(65) **Prior Publication Data**

US 2024/0094094 A1 Mar. 21, 2024

(30) **Foreign Application Priority Data**

Sep. 21, 2022 (CN) 202211153487.8

(51) **Int. Cl.**
G01M 99/00 (2011.01)
G01H 13/00 (2006.01)
G06N 20/00 (2019.01)

(52) **U.S. Cl.**
CPC ***G01M 99/005*** (2013.01); ***G01H 13/00*** (2013.01); ***G06N 20/00*** (2019.01)

(58) **Field of Classification Search**
CPC G01M 99/005; G01M 99/007; G01M 99/008; F04B 2201/0802; F04B 2201/0806; F04B 51/00; F01B 49/103; F04D 15/0088
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,825,657 A * 10/1998 Hernandez G01M 13/028 702/182
6,330,525 B1 * 12/2001 Hays F04D 15/0088 702/182
7,013,223 B1 * 3/2006 Zhang F02M 65/003 702/34
7,031,873 B2 * 4/2006 Song G01P 3/44 702/145
7,653,512 B2 1/2010 Cheung et al.
7,664,618 B2 2/2010 Cheung et al.
8,190,592 B1 * 5/2012 Bayardo G06F 16/3347 707/706
8,401,806 B2 * 3/2013 Borsting F04D 15/0088 702/56
10,119,537 B2 * 11/2018 Wetherill F04B 49/06
10,311,703 B1 * 6/2019 Hayzen G06F 16/21
(Continued)

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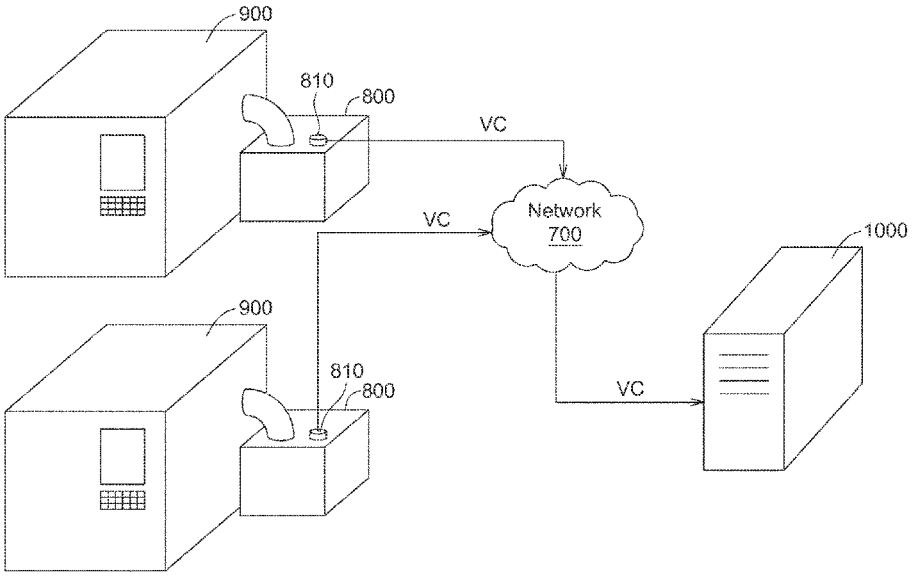
(57) **ABSTRACT**

A pump health analysis method and a pump health analysis device using the same are provided. A standard vibration curve of a standard pump is obtained. The standard vibration curve is converted from a time domain to a frequency domain to obtain a first frequency distribution curve. A sample vibration curve of a sample pump is obtained. The sample vibration curve is converted from the time domain to the frequency domain to obtain a second frequency distribution curve. The first frequency distribution curve is compared with the second frequency distribution curve by using a cosine similarity algorithm to obtain a health index of the sample pump.

18 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

10,316,849	B2 *	6/2019	Munk	G01M 99/008
10,393,621	B2 *	8/2019	Jaramillo-Velasques	G06N 3/08
10,458,224	B2 *	10/2019	Dickenson	E21B 47/008
10,801,491	B2 *	10/2020	Urdaneta	E21B 43/2607
11,215,535	B2 *	1/2022	Huang	B25J 9/1674
11,429,900	B1 *	8/2022	Alvarenga Marinelli	H04R 3/005
11,493,404	B2 *	11/2022	Tobon-Mejia	G01H 1/003
11,746,645	B2 *	9/2023	Vittal	E21B 47/008 166/250.15
11,754,592	B1 *	9/2023	Bechhoefer	G01P 15/097 702/69
12,067,486	B2 *	8/2024	Liang	G06N 3/044
12,135,543	B2 *	11/2024	Gabaldon	G01H 1/003
2005/0286753	A1 *	12/2005	Ho	H04N 17/04 348/E17.005
2008/0234964	A1 *	9/2008	Miyasaka	G01M 13/04 702/113
2010/0082275	A1 *	4/2010	Borsting	F04D 15/0066 702/56
2015/0095100	A1 *	4/2015	Vittal	G05B 23/0213 700/282
2018/0087499	A1 *	3/2018	Zhang	F04B 49/08
2019/0287005	A1 *	9/2019	Subramaniyan	G06N 5/04
2022/0018707	A1 *	1/2022	Chen	G01H 1/06
2023/0307127	A1 *	9/2023	Zhi	G16H 10/60

* cited by examiner

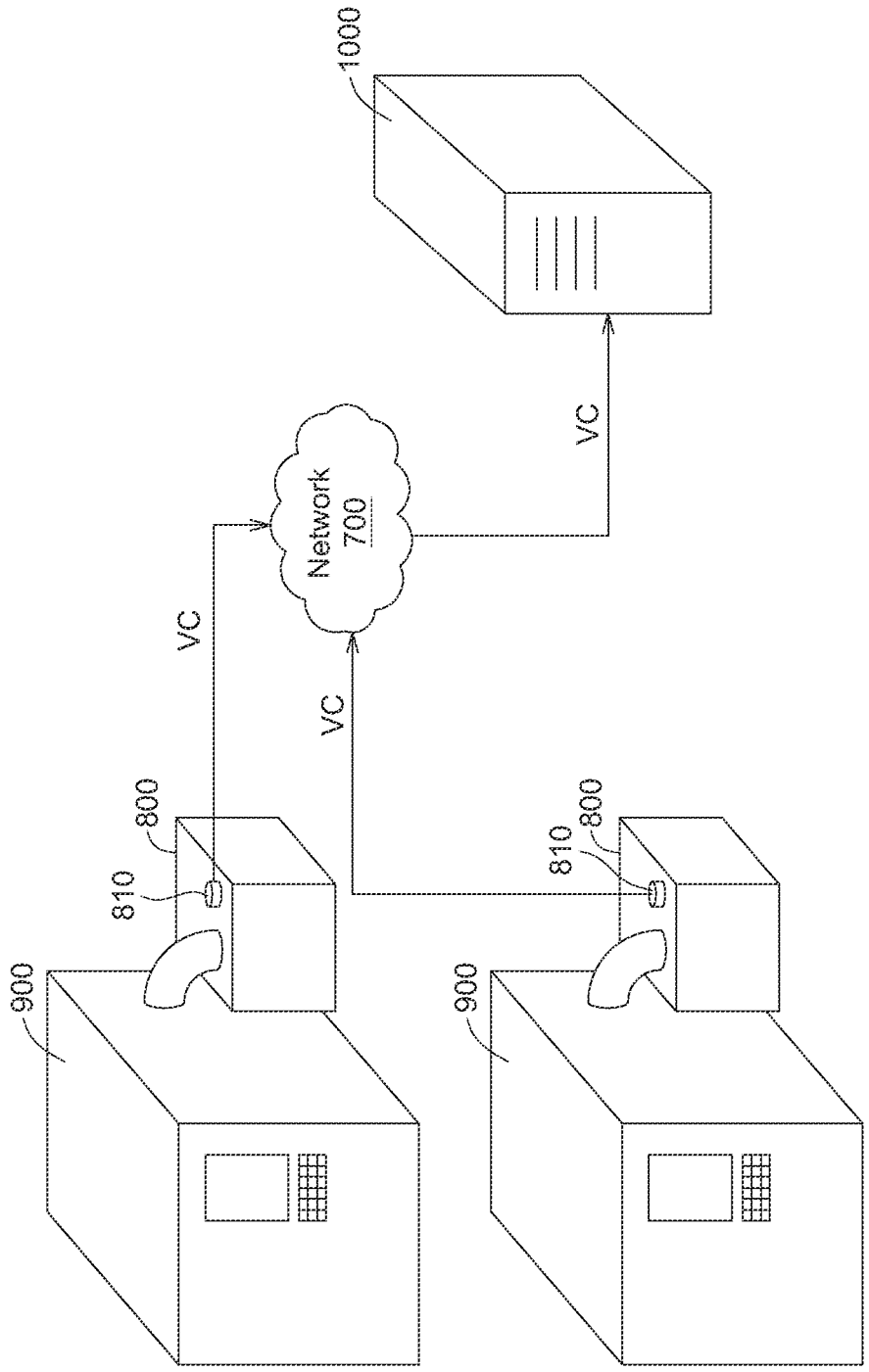


FIG. 1

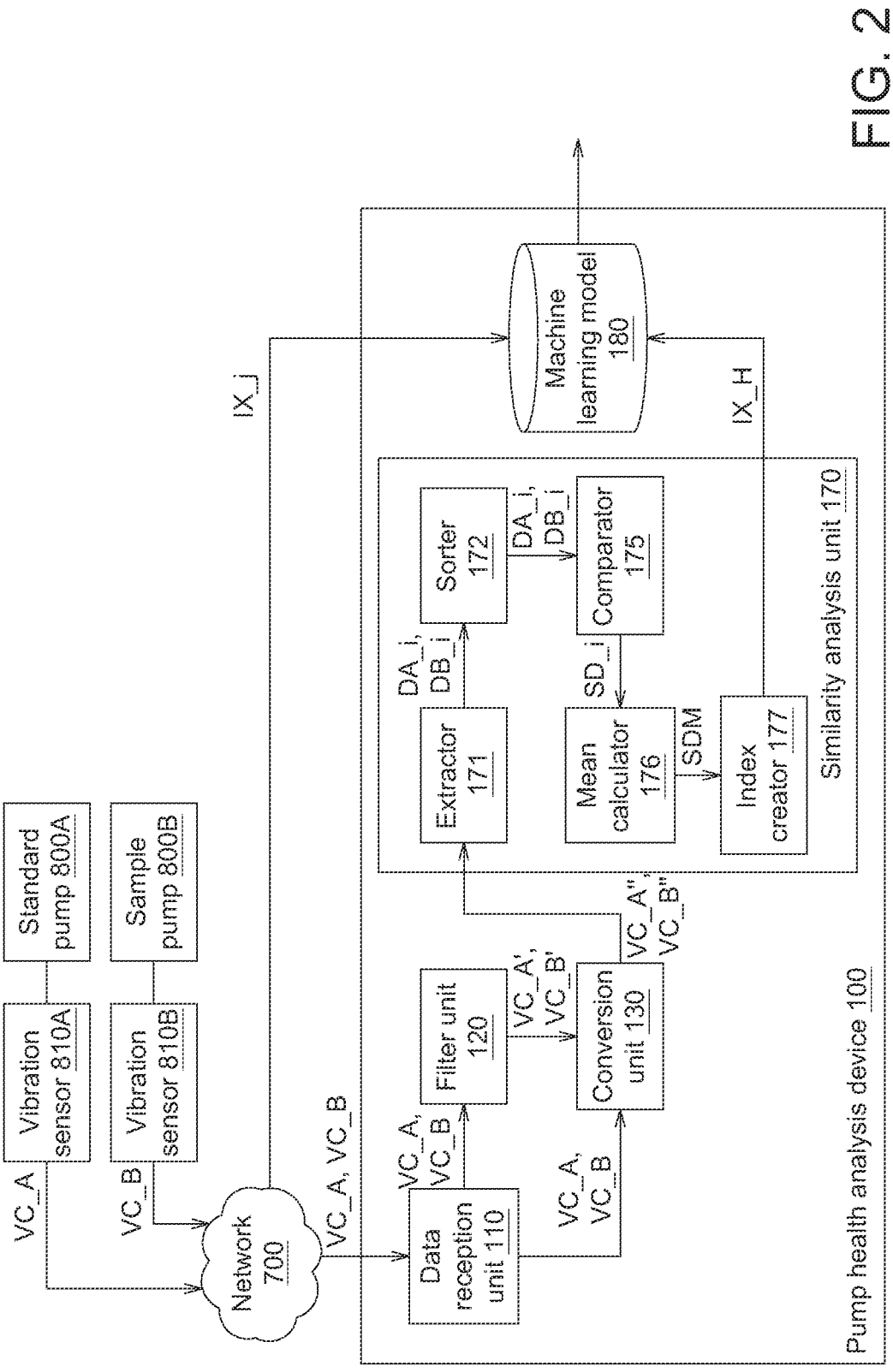

Standard pump 800A
Sample pump 800B
Vibration sensor 810A
Vibration sensor 810B
VC_A
VC_B
Network 700
VC_A, VC_B
IX_j
Machine learning model 180
IX_H
Pump health analysis device 100
Data reception unit 110
VC_A, VC_B
Filter unit 120
VC_A', VC_B'
Conversion unit 130
VC_A'', VC_B''
Similarity analysis unit 170
Extractor 171
DA_i, DB_i
Sorter 172
DA_i, DB_i
Comparator 175
SD_i
Mean calculator 176
SDM
Index creator 177

FIG. 2

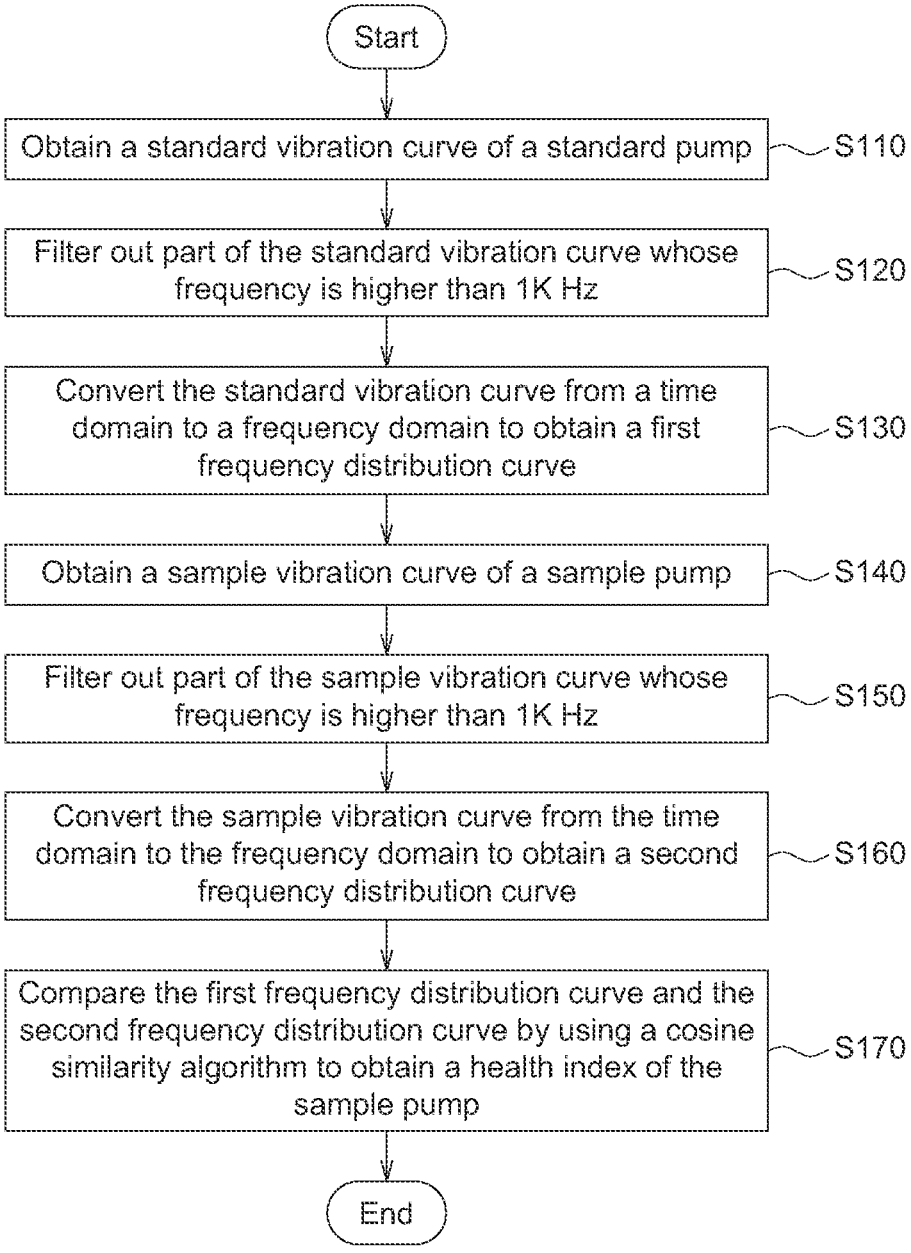

Start
Obtain a standard vibration curve of a standard pump
S110
Filter out part of the standard vibration curve whose frequency is higher than 1K Hz
S120
Convert the standard vibration curve from a time domain to a frequency domain to obtain a first frequency distribution curve
S130
Obtain a sample vibration curve of a sample pump
S140
Filter out part of the sample vibration curve whose frequency is higher than 1K Hz
S150
Convert the sample vibration curve from the time domain to the frequency domain to obtain a second frequency distribution curve
S160
Compare the first frequency distribution curve and the second frequency distribution curve by using a cosine similarity algorithm to obtain a health index of the sample pump
S170
End

FIG. 3

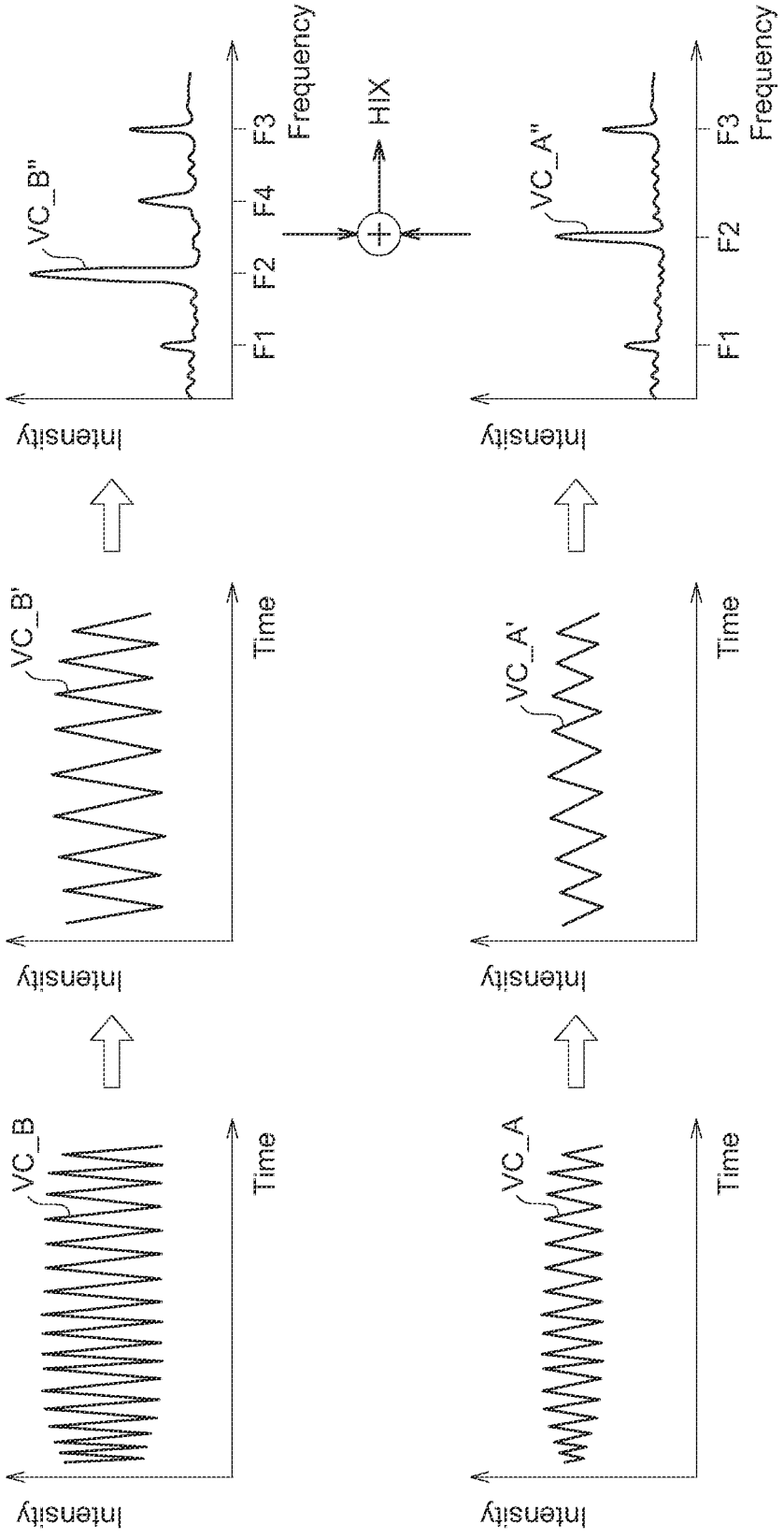

VC_B
Time
Intensity
VC_B'
Time
Intensity
VC_B"
F1
F2
F4
F3
Frequency
Intensity
HIX
VC_A
Time
Intensity
VC_A'
Time
Intensity
VC_A"
F1
F2
F3
Frequency
Intensity

FIG. 4

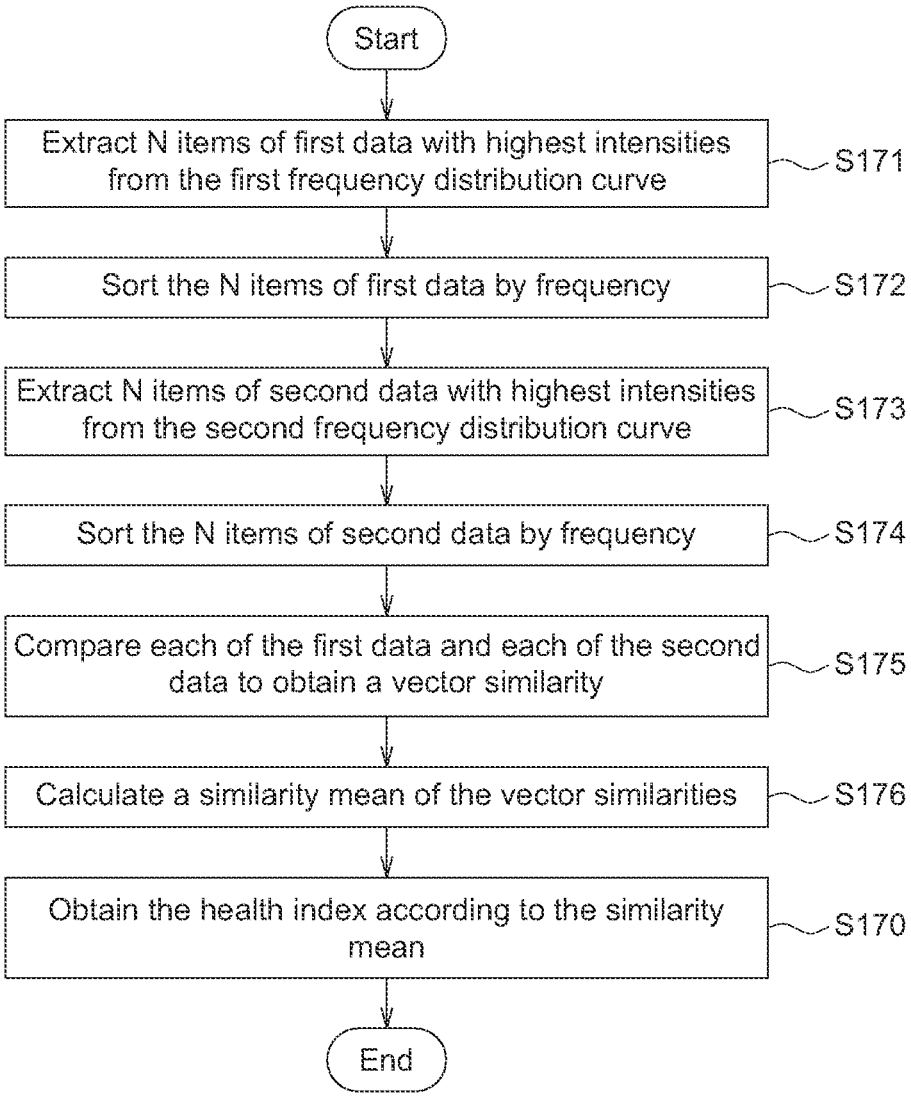

Start
Extract N items of first data with highest intensities from the first frequency distribution curve
S171
Sort the N items of first data by frequency
S172
Extract N items of second data with highest intensities from the second frequency distribution curve
S173
Sort the N items of second data by frequency
S174
Compare each of the first data and each of the second data to obtain a vector similarity
S175
Calculate a similarity mean of the vector similarities
S176
Obtain the health index according to the similarity mean
S170
End

FIG. 5

PUMP HEALTH ANALYSIS METHOD AND PUMP HEALTH ANALYSIS DEVICE USING THE SAME

This application claims the benefit of People's Republic of China application Serial No. 202211153487.8, filed Sep. 21, 2022, the subject matter of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates in general to an analysis method and an analysis device using the same, and more particularly to a pump health analysis method and a pump health analysis device using the same.

Description of the Related Art

In a semiconductor factory, many items of semiconductor equipment are equipped with a pump to vacuum or ventilate the gas. However, if the pump suddenly breaks down after a long period of operation, the manufacturing process of semiconductor will be severely affected, and a whole batch of wafers may even be damaged.

Therefore, it has become a prominent task for the research personnel to develop and provide a technology for monitoring and predicting the health of the pump.

SUMMARY OF THE INVENTION

The invention is directed to a pump health analysis method and a pump health analysis device using the same capable of quickly analyzing the health state of a sample pump using a cosine similarity algorithm according to an analysis of comparison between the vibrations of the sample pump with the vibrations of a standard pump.

According to one embodiment of the present invention, a pump health analysis method is provided. The pump health analysis method includes the following steps. A standard vibration curve of a standard pump is obtained. The standard vibration curve is converted from a time domain to a frequency domain to obtain a first frequency distribution curve. A sample vibration curve of a sample pump is obtained. The sample vibration curve is converted from the time domain to the frequency domain to obtain a second frequency distribution curve. The first frequency distribution curve is compared with the second frequency distribution curve by using a cosine similarity algorithm to obtain a health index of the sample pump.

According to another embodiment of the present invention, a pump health analysis device is provided. The pump health analysis device includes a data reception unit, a conversion unit and a similarity analysis unit. The data reception unit is configured to obtain a standard vibration curve of a standard pump and a sample vibration curve of a sample pump. The conversion unit is configured to convert the standard vibration curve from a time domain to a frequency domain to obtain a first frequency distribution curve and to convert the sample vibration curve from the time domain to the frequency domain to obtain a second frequency distribution curve. The similarity analysis unit is configured to compare the first frequency distribution curve and the second frequency distribution curve by using a cosine similarity algorithm to obtain a health index of the sample pump.

The above and other aspects of the invention will become better understood with regard to the following detailed description of the preferred but non-limiting embodiment(s). The following description is made with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of semiconductor equipment and pumps according to an embodiment.

FIG. **2** is a block diagram of a pump health analysis device according to an embodiment.

FIG. **3** is a flowchart of a pump health analysis method according to an embodiment

FIG. **4** exemplifies each step of FIG. **3**.

FIG. **5** is a detailed flowchart of step S**170** according to an embodiment.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, a schematic diagram of semiconductor equipment **900** and pumps **800** according to an embodiment is shown. Each of the pumps **800** is connected to the semiconductor equipment **900** to extract or vacuum the gas. For example, these pumps **800** could be identical and could be used for different kinds of semiconductor equipment **900**.

After a long period of operations, the vibrations of the pump **800** may change. In the present embodiment, a vibration curve VC of the pump **800** is obtained by a vibration sensor **810**. After the vibration curve VC is transmitted to a pump health analysis device **100** through a network **700**, the health index of the pump **800** can be quickly analyzed according to the vibration curve VC.

Referring to FIG. **2**, a block diagram of the pump health analysis device **100** according to an embodiment is shown. The pump health analysis device **100** includes a data reception unit **110**, a filter unit **120**, a conversion unit **130**, a similarity analysis unit **170** and a machine learning model **180**. Brief descriptions of the functions of each element are disclosed below. The data reception unit **110** is used to receive various types of data from such as a network transmission module, a transmission line, an LTE module, a Bluetooth module, or a combination thereof. The filter unit **120** is used to filter signals. The conversion unit **130** is used to convert signals. The similarity analysis unit **170** is used to analyze similarity. After the machine learning model **180** is trained, the machine learning model **180** can output forecasting information according to various characteristic indexes inputted thereto. The filter unit **120**, the conversion unit **130**, the similarity analysis unit **170** and machine learning model **180** could be realized by a chip, a circuit, a circuit board, a code, a storage device that stores the code, or a combination thereof.

The similarity analysis unit **170** includes an extractor **171**, a sorter **172**, a comparator **175**, a mean calculator **176** and an index creator **177**. The extraction element **171**, the sorter **172**, the comparator **175**, the mean calculator **176** and the index creator **177** are used to execute various calculations of similarity analysis.

In the present embodiment, as indicated in FIG. **2**, the standard pump **800**A is a pump that has just been calibrated or new production, and therefore has the best state of health. The sample pump **800**B is a pump to be measured. In the present embodiment, the health state of the sample pump **800**B can be quickly analyzed according to a comparison between the sample pump **800**B and the standard pump

800A. The operations of each element of the pump health analysis device **100** are disclosed below with a flowchart.

Refer to FIG. **2** to FIG. **4**. FIG. **3** is a flowchart of a pump health analysis method according to an embodiment. FIG. **4** exemplifies each step of FIG. **3**. In step S**110**, a standard vibration curve VC_A of a sample pump **800**A is obtained by a data reception unit **110**. The standard vibration curve VC_A is obtained by a vibration sensor **810**A arranged on the sample pump **800**A. Although the sample pump **800**A is at the best state, it still has a certain degree of vibrations. The standard vibration curve VC_A records the vibration situation of the sample pump **800**A within 0.2, 0.3, 0.4, or 0.5 seconds.

Next, the method proceeds to step S**120**, part of the standard vibration curve VC_A whose frequency if higher than 1K Hz is filtered out by the filter unit **120**. The frequencies higher than 1K Hz normally are noises, therefore the filter unit **120** filter out these noises to increase the accuracy in subsequent analysis. As indicated in FIG. **2** and FIG. **4**, after the standard vibration curve VC_A is inputted to the filter unit **120**, the standard vibration curve VC_A is filtered to obtain a standard vibration curve VC_A'. In an embodiment, step S**120** can be omitted and the standard vibration curve VC_A can be directly inputted to the conversion unit **130**.

Then, the method proceeds to step S**130**, the standard vibration curve VC_A' (or standard vibration curve VC_A) is converted from a time domain to a frequency domain by the conversion unit **130** to obtain a first frequency distribution curve VC_A". In the present embodiment, the conversion unit **130** converts the standard vibration curve VC_A' (or standard vibration curve VC_A) using a Fourier transform technique. The first frequency distribution curve VC_A" records accumulative intensities of each frequency band. In the example of FIG. **4**, the first frequency distribution curve VC_A" has peaks at frequencies F**1**, F**2**, and F**3**.

Then, the method proceeds to step S**140**, a sample vibration curve VC_B of the sample pump **800**B is obtained by the data reception unit **110**. The sample vibration curve VC_B is obtained by a vibration sensor **810**B arranged on the sample pump **800**B. Normally, after a long period of operation, the vibration situation of the sample pump **800**B may change. The sample vibration curve VC_B records the vibration situations of the sample pump **800**B within 0.2, 0.3, 0.4, or 0.5 seconds. To compare the sample pump **800**B with the sample pump **800**A, the time lengths recorded in the sample vibration curve VC_B are the same as that recorded in the standard vibration curve VC_A.

Next, the method proceeds to step S**150**, part of the sample vibration curve VC_B whose frequency is higher than 1K Hz is filtered out by the filter unit **120**. The frequencies higher than 1K Hz normally are noises, therefore the filter unit **120** filter off these noises to increase the accuracy of subsequent analysis. As indicated in FIG. **2**, FIG. **4**, after the sample vibration curve VC_B is inputted to the filter unit **120**, the sample vibration curve VC_B is filtered to obtain a sample vibration curve VC_B'. In an embodiment, step S**180** can be omitted and the sample vibration curve VC_B can be directly inputted to the conversion unit **130**. To maintain a consistent benchmark of comparison, step S**120** and step S**150** must be concurrently deleted or maintained.

Then, the method proceeds to step S**160**, the sample vibration curve VC_B' (or sample vibration curve VC_B) is converted from the time domain to the frequency domain by the conversion unit **130** to obtain a second frequency distribution curve VC_B". In the present embodiment, the conversion unit **130** converts the sample vibration curve VC_B' (or sample vibration curve VC_B) using the Fourier transform technique. The second frequency distribution curve VC_B" records accumulative intensities of each frequency band. In the example of FIG. **4**, the second frequency distribution curve VC_B" has peaks at frequencies F**1**, F**2**, F**3** and F**4**. In comparison to the first frequency distribution curve VC_A", the second frequency distribution curve VC_B" has one more frequency peak, and the intensity at the frequency F**2** is significantly stronger than that in the first frequency distribution curve VC_A".

Next, the method proceeds to step S**170**, the similarity analysis unit **170** compares the first frequency distribution curve VC_A" and the second frequency distribution curve VC_B" by using a cosine similarity algorithm to obtain a health index IX_H of the sample pump **800**B.

Refer to FIG. **2** and FIG. **5**. FIG. **5** a detailed flowchart of step S**170** according to an embodiment. Step S**170** includes steps S**171** to S**177**. In step S**171**, N items of first data with N highest intensities are extracted from the first frequency distribution curve VC_A" by the extractor **171**. N is such as 100. Take Table 1 for instance. The first frequency scope corresponding to each item of data of the first frequency distribution curve VC_A" is such as 3.6 Hz. The first frequency distribution curve VC_A" is exemplarily divided into 278 items of data, and the first 100 items of the first data with the 100 highest intensities are extracted from the 278 items of data and defined as the first data DA_i.

TABLE 1

Frequency (Hz)	Intensity (dB)	Extracted?
0-3.6	XX	
3.6-7.2	XXX	V
. . .	. . .	
993.6-997.2	XXX	V
997.2-1000	XX	

Next, the method proceeds to step S**172**, the sorter **172** sorts these first data DA_i by frequency. For instance, these first data DA_i are sorted using a quick sorting method.

Then, the method proceeds to step S**173**, the N items of the second data with the N highest intensities are extracted from the second frequency distribution curve VC_B" by the extractor **171**. N is such as 100. The second frequency scope corresponding to each item of data of the second frequency distribution curve VC_B" is also 3.6 Hz. The second frequency distribution curve VC_B" is exemplarily divided into 278 items of data, and the first 100 items of second data with the 100 highest intensities are extracted from the 278 items of data and defined as the second data DB_i.

Next, the method proceeds to step S**174**, he sorter **172** sorts these second data DB_i by frequency. For instance, these second data DB_i are sorted using the quick sorting method.

Then, the method proceeds to step S**175**, the comparator **175** compares each of the first data DA_i and each of the corresponding second data DB_i to obtain a vector similarity. The frequency and the intensity of each item of the first data DA_i form a vector; the frequency and the intensity of each item of the second data DB_i also form a vector. The comparator **175** compares the N corresponding vectors to obtain N items of vector similarities SD_i.

Next, the method proceeds to step S**176**, a similarity mean SDM of these vector similarities SD_i is calculated by the mean calculator **176**. In the present step, a weighted average

of these vector similarities SD_i can be calculated by the mean calculator **176** according to the sensitivity information. For instance, if a particular model of pump has significant vibration within certain particular frequency scopes, this indicates that this pump will be broken soon. Meanwhile, a larger weight can be assigned to this particular frequency scope through the setting of the sensitivity information.

Then, the method proceeds to step S**177**, a health index IX_H is obtained by the index creator **177** according to the similarity mean SDM. The relationship between the similarity mean SDM and the health index IX_H is such as a curve, and the index creator **177** can obtain a corresponding health index IX_H according to the similarity mean SDM.

After obtaining the health index IX_H, the pump health analysis device **100** can immediately determine the health situation of the health index IX_H. In the present embodiment, as long as the data of a standard vibration curve VC_A of the sample pump **800**A is stored in advance, the sample pump **800**B can be compared and analyzed every 0.3 second. The pump health analysis method of the present embodiment is extremely fast, and does not need to be trained with big data which is time-consuming, and therefore is very suitable to be used in the real-time monitoring of production line. If the health situation of a pump is found to be unsatisfactory, this pump can be replaced immediately to avoid causing problems to the manufacturing process.

As indicated in FIG. **2**, the health index IX_H can also be inputted to the machine learning model **180** to perform training. The machine learning model **180** can be trained with such as 12 characteristic indexes IX_j (such as temperature, total time of use, sound, and the number of times of oil change) and the historical data of the health index IX_H. The obtained characteristic indexes IX_j and the health index IX_H can be inputted to the trained machine learning model **180** to predict a residual lifetime of the sample pump **8008**.

According to the above embodiments, the pump health analysis device **100** can quickly analyze the health state of the sample pump **800**B using the cosine similarity algorithm according to an analysis of comparison between the vibration state of the sample pump **800**B and the vibration state of the sample pump **800**A.

While the invention has been described by way of example and in terms of the preferred embodiment(s), it is to be understood that the invention is not limited thereto. Based on the technical features embodiments of the present invention, a person ordinarily skilled in the art will be able to make various modifications and similar arrangements and procedures without breaching the spirit and scope of protection of the invention. Therefore, the scope of protection of the present invention should be accorded with what is defined in the appended claims.

What is claimed is:

1. A pump health analysis method, comprising:

obtaining a standard vibration curve of a standard pump;

converting the standard vibration curve from a time domain to a frequency domain to obtain a first frequency distribution curve;

obtaining a sample vibration curve of a sample pump;

converting the sample vibration curve from the time domain to the frequency domain to obtain a second frequency distribution curve; and

comparing the first frequency distribution curve and the second frequency distribution curve by using a cosine similarity algorithm to obtain a health index of the sample pump;

wherein the step of comparing the first frequency distribution curve and the second frequency distribution curve comprises:

extracting N items of first data with highest intensities from the first frequency distribution curve;

sorting the N items of first data by frequency;

extracting N items of second data with highest intensities from the second frequency distribution curve;

sorting the N items of second data by frequency;

comparing each of the first data and each of the second data to obtain a vector similarity;

calculating a similarity mean of the vector similarities; and

obtaining the health index according to the similarity mean.

2. The pump health analysis method according to claim **1**, further comprising:

filtering out part of the standard vibration curve whose frequency is higher than 1K Hz; and

filtering out part of the sample vibration curve whose frequency is higher than 1K Hz.

3. The pump health analysis method according to claim **1**, wherein in the step of calculating the similarity mean of the vector similarities, a weighted average of the vector similarities is calculated according to a frequency sensitivity information.

4. The pump health analysis method according to claim **1**, wherein the first data correspond to a plurality of first frequency scopes having identical width; the second data correspond to a plurality of second frequency scopes having identical width.

5. The pump health analysis method according to claim **4**, wherein each of the first frequency scopes has a width of 3.6 Hz; each of the second frequency scopes has a width of 3.6 Hz.

6. The pump health analysis method according to claim **1**, wherein N is 100.

7. The pump health analysis method according to claim **1**, wherein the first data are sorted via a quick sorting algorithm; the second data are sorted via the quick sorting algorithm.

8. The pump health analysis method according to claim **1**, wherein the health index is inputted to a machine learning model for training, and the machine learning model is used to predict a residual lifetime of the sample pump.

9. The pump health analysis method according to claim **1**, wherein the standard vibration curve records vibrations of the standard pump within 0.3 second, and the sample vibration curve records vibrations of the sample pump with 0.3 second.

10. A pump health analysis device, comprising:

a data reception unit configured to obtain a standard vibration curve of a standard pump and a sample vibration curve of a sample pump;

a conversion unit configured to convert the standard vibration curve from a time domain to a frequency domain to obtain a first frequency distribution curve, and to convert the sample vibration curve from the time domain to the frequency domain to obtain a second frequency distribution curve; and

a similarity analysis unit configured to compare the first frequency distribution curve and the second frequency distribution curve by using a cosine similarity algorithm to obtain a health index of the sample pump;

wherein the similarity analysis unit comprises:

an extractor configured to extract N items of first data with highest intensities from the first frequency

distribution curve and to extract N items of second data with highest intensities from the second frequency distribution curve;

a sorter configured to sort the first data and the second data by frequency;

a comparator configured to compare each of the first data and each of the second data to obtain a vector similarity;

a mean calculator configured to calculate a similarity mean of the vector similarities; and

an index creator configured to obtain the health index according to the similarity mean.

11. The pump health analysis device according to claim **10**, further comprising:

a filter unit configured filter out part of the standard vibration curve and part of the sample vibration curve whose frequency is higher than 1K Hz.

12. The pump health analysis device according to claim **10**, wherein the mean calculator calculates a weighted average of the vector similarities according to a sensitivity information.

13. The pump health analysis device according to claim **10**, wherein the first data correspond to a plurality of first frequency scopes having identical width; the second data correspond to a plurality of second frequency scopes having identical width.

14. The pump health analysis device according to claim **13**, wherein each of the first frequency scopes has a width of 3.6 Hz; each of the second frequency scopes has a width of 3.6 Hz.

15. The pump health analysis device according to claim **10**, wherein N is 100.

16. The pump health analysis device according to claim **10**, wherein the first data are sorted via a quick sorting algorithm; the second data are sorted via the quick sorting algorithm.

17. The pump health analysis device according to claim **10**, wherein the health index is inputted to a machine learning model for training, and the machine learning model is used to predict a residual lifetime of the sample pump.

18. The pump health analysis device according to claim **10**, wherein the standard vibration curve records vibrations of the standard pump within 0.3 second, and the sample vibration curve records vibrations of the sample pump with 0.3 second.

* * * * *